

# CEMENT AND LIME MANUFACTURE

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## The Maastricht Portland Cement Works, Holland.

By HAL GUTTERIDGE, A.M.I.Mech.E., M.I.E.I.

THE Maastricht works of the Eerste Nederlandsche Cement-Industrie (ENCI) is close to the frontiers of Holland, Germany, and Belgium and in the centre of an important industrial area with Dusseldorf in the east and Liege and Brussels in the west. The factory is situated on a bank of the Maas (or Meuse) shipping canal near Maastricht, which is connected with Antwerp by the Albert canal. This is convenient for the supply of the raw materials not found on the site, i.e. additional clay, gypsum, and coal, as well as for the despatch of cement.

The works has four kilns, and produces about 1,200 tons (7,200 barrels) of cement per day. When it was built twelve years ago by a Continental firm it was the largest cement works, built as one unit, in Europe; it has about the same capacity as the Great Lakes works at Buffalo, U.S.A., and is just over half the size of the Canada Cement No. 1 works at Montreal.

### Raw Materials.

The raw material is a light sandy-coloured soft argillaceous limestone or marl containing 80 to 90 per cent. of calcium carbonate. There is therefore no deficiency of calcareous matter but it is necessary to add further clayey material from outside sources. The material is coarse in texture and is just soft enough to be dug directly from the face by electrically-driven crawler-type mechanical shovels. The hardness of the material varies and, at a higher level, it used to be quarried and used as building stone. This material is harder than the grey chalk-marls of Bedfordshire, and somewhat similar to those in Oxfordshire; it is softer than the argillaceous limestones known as "cement-rock" of the Lehigh district of Pennsylvania or that used in the eastern provinces of Canada. No drilling or blasting is required except, infrequently, to bring down the material for convenience in handling by the power shovels when the face is high.

The quarry floor is about 30 ft. above the floor level of the works, so that it is a level haul to the raw-material preparation-mill. The distance between the point where the shovels are operating and the despatch point is not more than 1,000 yd.

The chemical properties of the raw material vary and the "wet" process was adopted because of the greater facility of that process, compared with the "dry" process, for mixing and correcting the proportions of the constituents.

#### Crushing Plant.

The only crushing treatment adopted is to pass the material through a single-roll mill, or a hammer-mill which is installed as a standby. Probably the only suitable equipment more simple than this is the "kibbling roll" used in England

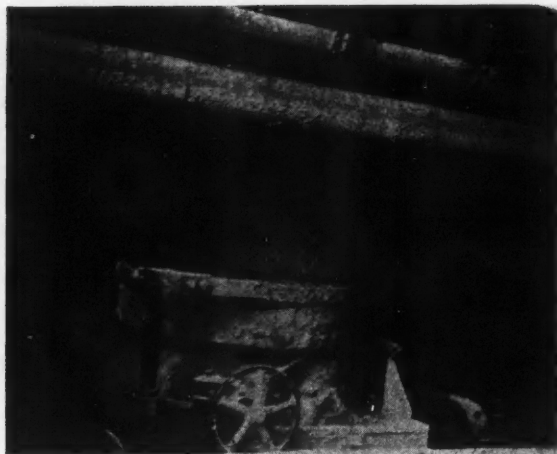


Fig. 1.—Feed to Washmill.

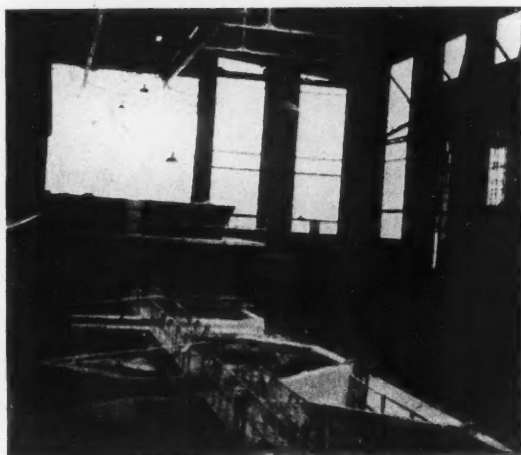
for breaking chalk when it contains no flints; this comprises two parallel shafts revolving at slightly different speeds, upon which are mounted "teeth" which are staggered so as to clear their opposite number something like the "live-roll grizzly" used in the U.S.A. and Canada. As the Maastricht works has to deal with flints in the raw material the latter type would not be suitable. Large flints are hand picked from a belt and the smaller ones are removed from the bottom of the washmills as in common practice.

The material from the inclined belt conveyor is delivered on to a horizontal belt conveyor, the frame of which can be traversed. The direction of the belt of the traversing conveyor can be reversed, so that, without using a "plough" scraper, material can be deposited directly into any of the four washmill hoppers along the line of the building. These large hoppers are the only lump limestone

storage in the works and are of ample capacity. The feeding arrangement for supplying the marl to the washmill is shown in *Fig. 1* and is of the type employing a rotating table 8 ft. 4 in. in diameter with a vertically movable collar, the rate of feed depending on the angle of repose of the material and the speed of rotation of the mill.

### Washmills.

The washmill house (*Fig. 2*) is typical of the sturdy construction evident throughout the factory. Additional clay, delivered by barge, is taken to the washmills by an electric overhead mono-rail travelling grab, the two lines for which are seen above the washmills in *Fig. 2*. The choice of the method of transport was influenced by the site, which is a narrow strip of land only about



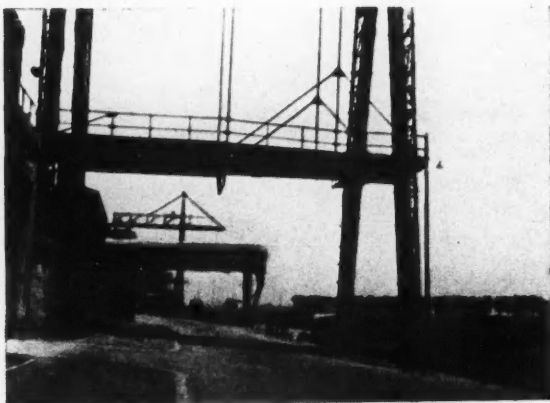
**Fig. 2.—Washmills.**

1,000 ft. wide between the canal and the cliff. If a bridge-type travelling grab had been used to operate over the barge, the storage, and the washmill, there would not have been sufficient space at right angles to the canal to accommodate the storage and washmills in line, and the same remarks apply to any form of ground railway. A belt-conveyor would not be practical in extracting clay from beneath the storage. The only practical alternative to the monorail grab would be to reduce the clay to slurry, store it in that form, and pump it to the washmills, which would require slightly more space, more costly plant, and more power to keep the slurry agitated than the present arrangement needs.

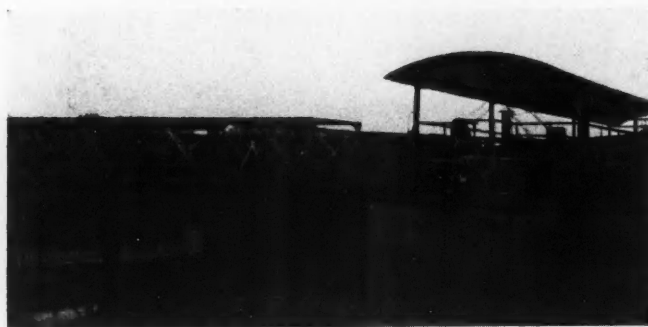
The clay is taken from barges on the canal (on the right of *Fig. 3*), over the road (protected by the platform), and into the storage on the ground shown in *Fig. 4*. From there it is taken at right angles into the washmill house seen in

*Fig. 5.* Normally the clay is deposited into hoppers over the two last washmills seen in *Fig. 2*, and the proportioning and mixing with the chalk slurry take place in a trough running parallel to, and at the back of, the washmills. A monorail grab (*Fig. 5*) is used for handling the clay.

All transport and handling of slurry are carried out by compressed air. By this method it is conveyed to the preliminary mixers, to the three trunnion-



**Fig. 3.—Transporting Clay from Barges.**



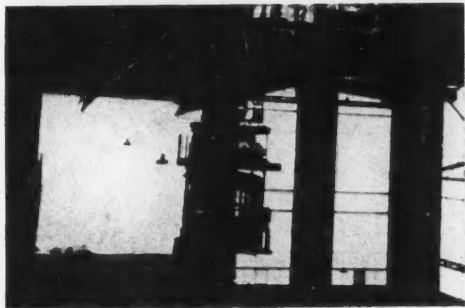
**Fig. 4.—Clay Storage in Left Foreground.**

bearing multi-compartment mills, to the final slurry mixing tanks (of which there are eight), and finally to the kilns. All agitation of the slurry is by the same system.

The choice of the system of agitating the slurry by compressed air was probably influenced by two main factors, (1) the restricted area available, and (2) if the slurry is transported by compressed air, the same equipment with some

small additions can be used for both purposes. The only mechanical part in the eight slurry tanks is a small rotating scraper at the bottom of each.

On account of the limited ground area it would not have been practical to install either (a) the sun-and-planet type of mixer, usually 100 ft. diameter, so popular in England which has, on a centrally-pivoted lattice girder, four revolving agitators with vertical spindles set equidistant along its length, or (b) the traveling-bridge type of mixer, up to 125 ft. in length, frequently met with in the



**Fig. 5.—Washmill House, showing Monorail Grab for Handling Clay.**



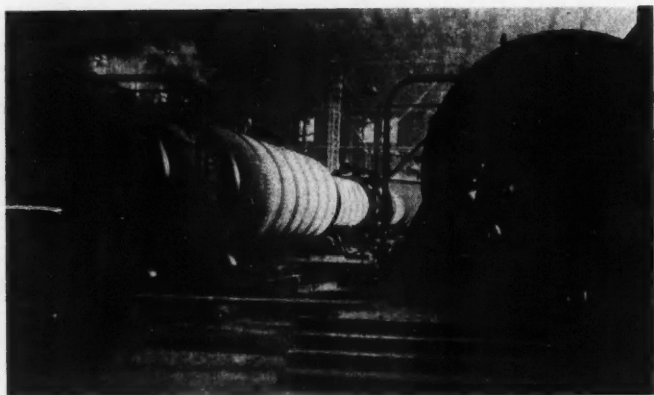
**Fig. 6.—Feed End of Kilns.**

U.S.A., where the bridge, having two or three mechanical agitating shafts mounted thereon, spans across the tank and moves on rails on the side walls. In this type the trip, there and back, usually takes fifteen minutes and the agitation is augmented if necessary by compressed air. *Fig. 6* shows the four kilns from the feed end and *Fig. 7* is a view from the firing end.

#### **Kilns.**

The arrangement of the four kilns is orthodox. The idea that the value of the heat lost from a kiln exposed to the weather, together with the cost of the

more rapid deterioration of the kiln shell, is less than the interest on the cost of a building to house the kiln, finds no expression at this works. The clinker-cooling arrangements are integral and in line with the kiln and can be seen in *Fig. 7*. This illustration gives a good idea of the ample space allowed between the kilns,



**Fig. 7.—Firing End of Kilns.**



**Fig. 8.—Cooling Clinker with Running Water.**

and shows the cooling system to reduce the temperature of the clinker by the application of water running over the circumferentially-fluted portion of the kiln in addition to the air for combustion which enters through the controllable circular ports seen at the end of the right-hand kiln. *Fig. 8* shows the fluted

portion with water dripping off. A further method of cooling the kiln shell at the burning zone by water sprays is seen in *Fig. 7* immediately in front of the second supporting tyre towards the feed-end of the kiln. A closer view of this is given in *Fig. 9*, where water is shown being sprayed in the space between the shell and the floor but without impinging on either. With an atmospheric temperature outside the building of 65 deg. F., the temperature on the floor between one of the kilns and one of the side walls was 90 deg. F. and on the feeding platform above the kilns it was only slightly warmer.

The slurry is introduced directly into the kilns without reducing the percentage of water therein, so that the kiln evaporates all the water contained in the slurry instead of the lesser amount which would be involved if some of the water had been removed.



**Fig. 9.—Cooling Kiln Shell at Burning Zone.**

When this works was built, the use of such equipment as slurry filters, calcinators, etc., was not so well established as it is to-day. Such additional equipment depends for its success upon a number of factors, including the nature of the slurry, the practicability of adding the equipment to existing plant, and the possibility of making use of the additional output from the kilns or, conversely, the value of the fuel saved. The fact that the kilns at Maastricht are only 225 ft. long suggests at least one condition favourable to ancillary assistance.

#### **Clinker Crushing.**

The clinker has an additional treatment not usually found in Britain, Canada, or the U.S.A., namely, preliminary crushing in roller mills before it is passed to storage. With most materials the clinker issuing from the kilns ranges in size from dust to the dimensions of a small pigeon's egg. Normal compartment mills can handle the usual maximum sizes of clinker with ease so that the presence

of a preliminary clinker crushing unit suggests either unusually large clinker or the sharing of the work with the clinker grinding mills.

This question of relieving the clinker mills by the preliminary crushing of the largest sizes of clinker for the purpose of increasing the overall efficiency of the crushing department depends upon the type of clinker which will be produced, its physical properties, its maximum size, and the proportions of each size. Into the account will be taken, on the one side, the increased efficiency of the clinker grinding mill due to a smaller maximum size of clinker without necessarily an increase in the proportion of dust, improved relation between the sizes of the grinding media, and decreased power consumption for the same output. On the other side, the additional equipment and conveyors necessary for the preliminary crushing, together with extra handling space, and power required are among the items that have to be balanced.

The hot clinker is taken from the kilns to the preliminary crushers by a steel-bucket conveyor and then by elevators and a 300-ft. belt conveyor to the clinker store. The clinker can be evenly distributed in either of the sections of the store, which are intended for special or ordinary clinker, with a separate section for gypsum. The extraction is from tunnels under the storage by orthodox movable swing chutes with belt conveyors.

Of the two usual forms of clinker depositing, namely, a movable trip on a belt conveyor or an overhead travelling crane, the choice depends on the method of conveying all the raw and semi-prepared materials at the works. At every works it is necessary to receive and store limestone or chalk, clay, gypsum, coal, and clinker. At a few places the chalk and clay are reduced to slurry at the quarry and pumped to the works, but usually these raw materials are received and stored in the solid "dry" form.

The first attempt at the solution of the storage problem will be an endeavour to carry out all or as many as possible of these services at one place so as to reduce the space occupied and the equipment needed. This can be done efficiently by an overhead travelling crane of wide span and high clearance, capable of moving along the elevated track at 400 ft. per minute. The grab picks up and deposits any of the materials anywhere in the piling area, and also grabs them up again to deliver them to their next destination. The movable trip, on the other hand, requires a complementary tunnel reclaiming conveyor to complete the extraction, the principal objection to which is that only about half the contents of the pile will flow to the conveyor by gravity. This resolves itself into a choice of building sloping sides to the container walls, having a large dead storage, or using some means such as drag scrapers to bring the "dead" material to the feed openings. Such a centralised arrangement may not, however, suit the general arrangement of the works, which will be influenced by the size, shape, and levels of the site, the position of the quarry, and the points of entry of the other raw materials. All these factors have had a very definite bearing on the planning of the works at Maastricht.

The centralisation of the storage presupposes the arrangement of all portions of the plant so that the storage is the focal point. Such an arrangement is not consistent with the ideal straight-line flow: Raw materials—preparation—mixing—calcining—clinker storage—grinding—cement. If the combined storage is between the firing-end of the kilns and the clinker grinding mills, it is well placed for handling clinker, coal, and gypsum, but it requires the raw material preparation plant to be at the side of the kilns, which is not always the best position as it requires a wider strip of land and is inconvenient if the factory is to be extended.

At Maastricht, in the narrow strip of land available, such an arrangement was out of the question and the other extreme has been adopted where each material is handled and stored in separate places. The quarried material is brought in train loads to the side remote from the canal and put straight through the preparation plant and stored in hoppers above the washmills; the clay and gypsum are taken directly from barges by an overhead travelling grab to their respective piles within the works; the coal is separately handled in the same way by a further crane of similar type; the clinker is conveyed to storage by a belt; and the slurry is pneumatically transported to storage. All the materials except the clinker, the quarried material, the slurry, and the finished products, are rehandled from the piles by the same monorail grab which deposited them. The clinker is withdrawn through underground tunnels, and the quarried material is fed to the washmills by rotating tables. Thus, excluding the storage of the finished products, there are five separate storage points served by five separate transporter units. The clinker from the clinker store, together with the requisite amount of gypsum, are taken by the belts and elevator to the five three-chamber cement mills from where the finished cement is pneumatically conveyed by pumps to the cement store, where it is fed to bags or barrels as required.

### **Powdered Fuel.**

The coal is dried in rotary dryers and ground in compartment mills, and the powdered fuel is conveyed pneumatically to the hoppers in the kiln house. From the hoppers it is extracted by double-screw extractors to give a constant and regular feed into the air stream conveying it to the kiln. Those who favour the "unit" method of coal reduction and direct injection into the kiln, as opposed to the "central" system as instanced above, claim that by performing the whole process in one pulverising machine no storage of the fuel in powdered form is required and therefore the risk of fire or explosion is reduced; that separate drying of the coal is not required as the fuel is pulverised in the presence of hot air drawn in from the clinker-cooling equipment which constitutes the "primary" air for combustion; and that the compactness of the equipment and the complete absence of dust are advantageous. In favour of the "central" system it is pointed out that there is little risk of fire or explosion in the storing of coal in powdered form as the quantities stored are not great, and that the preliminary drying of the coal before reduction is the only proper way to treat coal if and when it arrives in the kiln it is to "flash" into flame. It is contended that the

momentary exposure of the coal to heat while it is passing through the pulveriser is not a satisfactory method of drying coal and does not properly prepare it for the kiln.

#### **Electro-Static Precipitators.**

Each kiln has a separate and complete installation of Lodge-Cotterell electrostatic precipitators, which permit the removal of the saleable dust and allow the emission of only a faint haze from the chimney stacks. This equipment was installed as part of the original design. The quantity of dust handled amounts to 15 per cent. of the clinker by weight, so that about 180 tons per day are handled from the four kilns. Half of this—the finer particles—is saleable as a fertilizer or for a filler for asphalt road mixtures.

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### **Water and Air in Concrete.**

THE problem of avoiding pitting on concrete surfaces has been attacked in a new way by the U.S. Bureau of Reclamation, whose experiments are described in "Concrete," March, 1940, by Mr. C. O. Crane. This work, which is still in progress, has met with some success. It was known that surface voids are larger and more prevalent when concrete is cast under a sloping form, such as that for the face of a spillway. The studies were therefore devoted chiefly to surfaces produced under this adverse condition.

Early observations disclosed that smooth-formed surfaces, often apparently free from pitting, lie over voids covered by a mortar film. A little rubbing or wire brushing exposes many of these hidden pits and reveals a condition far from conducive to durability. One of the forms was provided with a glass plate as an upper sloping surface, so that the concrete might be observed during placing and compacting. Immediately after vibration was started, bubbles commenced to accumulate against the glass. These bubbles, when pierced by a pipette, disappeared and left no trace of water in the tube, thus proving that they were composed almost entirely of air. Corroborative tests were made, using a piece of transparent pyralin for the upper form, which permitted the bubbles to be removed easily through drill holes. A very small drill was used, and drilling was done slowly, particularly when the drill point approached the bubbles. When the drill pierced the pyralin, the bubbles collapsed instantly and the surrounding concrete (within 2 in. or 3 in. from the hole) underwent a pronounced jerk as it replaced the space previously occupied by the bubble. As this movement took place, little or no moisture appeared in the drill hole. However, even though the concrete showed very little "bleeding" at the top unformed surface, after approximately three minutes had elapsed the holes in the pyralin began to exude water. A surprising amount of water, so free from cement and fine sand as to be clear, drained from all the holes. From this it appears that if the development of voids is to be prevented, and concrete surfaces are to be improved, forms are necessary which will permit the free escape of air and at the same time be sufficiently absorbent to remove some of the accumulated excess water from the concrete near the face. It was discovered that, by covering absorbent insulating boards with a cheap muslin, bonding can be prevented and a concrete surface produced which is free from pits and possesses a pleasing appearance.

## The Chemical Analysis of Portland Cement.

In December last a committee of the American Society for Testing Materials accepted the following proposed tentative method of the chemical analysis of Portland cement. It is stated that in cases of dispute the results obtained according to sections 6, 11 and 13 of the Standard Methods of Sampling and Testing Portland Cement (A.S.T.M. designation C114-39) shall govern.

### Silicon Dioxide.<sup>1</sup>

1. (a) Mix thoroughly 0.5 g. of cement and about 0.5 g. of  $\text{NH}_4\text{Cl}$  in a 50 ml. beaker, cover the beaker with a watch glass, and add cautiously 5 ml. of  $\text{HCl}$  (sp. gr. 1.19), allowing the acid to run down the lip of the covered beaker. After the chemical action has subsided lift the cover, add 1 or 2 drops of  $\text{HNO}_3$  (sp. gr. 1.42), stir the mixture with a glass rod, replace the cover, and set the beaker on a water bath for 30 minutes.<sup>2</sup> During this time of digestion stir the contents occasionally and break up any remaining lumps to facilitate the complete decomposition of the cement. Fit a filter paper of medium fineness to a funnel, transfer the precipitate to the filter as completely as possible without dilution, and allow the solution to drain through. Scrub the beaker with a rubber policeman and rinse the beaker and policeman. Wash the filter two or three times with hot diluted  $\text{HCl}$  (1:99) and then with ten or twelve small portions of hot water, allowing each portion to drain through completely. Reserve the filtrate and washings for the determination of  $\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$ .

(b) Transfer the filter paper and residue to a weighed platinum crucible, dry, and ignite, at first slowly until the carbon of the paper is completely consumed without flaming and finally at 1,050 to 1,100 deg. C. for 1 hour. Weigh the residue as  $\text{SiO}_2$ .

### Aluminium Oxide and Ferric Oxide.

2. Determine  $\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$  by the procedure described in Section 7 of the Standard Methods of Sampling and Testing Portland Cement (A.S.T.M. Designation C 114-39) of the American Society for Testing Materials.

### Calcium Oxide.

3. Special Solution Required. Standard Potassium Permanganate (approximately 0.18 N).—Prepare a solution of  $\text{KMnO}_4$  on the basis of 5.634 g. per litre. The solution should not be filtered through any filter containing organic matter. It is most convenient to siphon off clear solution without disturbing the sediment on the bottom of the bottle. Standardise the solution with 0.75 g. of sodium oxalate oxidimetric standard furnished by the National Bureau of Standards (standard sample No. 40) according to the directions furnished with the sodium oxalate. If the burette reading is 62.77 ml., the solution contains 0.005634 g.

<sup>1</sup> This procedure, which covers the precipitation of silicon dioxide by treating cement with  $\text{NH}_4\text{Cl}$  and  $\text{HCl}$ , is based on National Bureau of Standards *Research Paper* 891, by Edwin E. Maczkowske, "A Rapid Method for the Determination of Silica in Portland Cement," *Journal of Research*, Nat. Bureau Standards, Vol. 16, No. 6, June 1936, p. 549.

<sup>2</sup> A hot plate may be used instead of a water bath if the heat is so regulated as to approximate that of a water bath.

of  $\text{KMnO}_4$  per millilitre which is equivalent to exactly 0.005 g. of CaO. Because of impurities and deterioration, the reading in the standardisation is not usually 62.77 ml. Calculate the value of the solution in terms of weight of CaO per millilitre as follows:

$$E = \frac{62.77 \times 0.005 \text{ g. per ml.}}{a}$$

where

$E$  = CaO equivalent of the solution in grams per millilitre, and

$a$  = Millilitres of solution required for standardisation.

4. Add a few drops of  $\text{NH}_4\text{OH}$  to the combined filtrates obtained in the aluminium oxide and ferric oxide precipitation and bring the solution to boiling. Add to the boiling solution 25 ml. of boiling ammonium oxalate (5 per cent.), and continue the boiling for 5 to 10 minutes. Then allow the solution to stand for 15 to 20 minutes. Filter, and wash the precipitate eight to ten times with hot water, the total amount of water used in rinsing the beaker and washing not to exceed 75 ml. Wash the precipitate back into the original beaker and add 200 ml. of water and 10 ml. of diluted  $\text{H}_2\text{SO}_4$  (1:1). Heat the solution just short of boiling and titrate it with the standard solution of  $\text{KMnO}_4$  to a permanent pink colour. Add the filter paper and break it up. Continue the titration slowly until the pink colour is permanent for 10 seconds. Calculate the percentage of CaO in the cement as follows

$$\text{CaO per cent.} = b \times E \times 200$$

where

$b$  = Millilitres of solution required for titration, and

$E$  = CaO equivalent of the solution in grams per millilitre.

#### Magnesium Oxide.

5. Acidify the filtrate from the determination of CaO with HCl and by boiling reduce the volume to about 250 ml. When the solution is cooled to room temperature, treat it with 10 ml. of a solution of  $(\text{NH}_4)_2\text{HPO}_4$  (10 per cent.) and 30 ml. of  $\text{NH}_4\text{OH}$  (sp. gr. 0.90). Stir the solution vigorously during the addition of  $\text{NH}_4\text{OH}$  and then for 10 to 15 minutes longer. Let the solution stand for at least 8 hours in a cool atmosphere, then filter. Wash the residue five or six times with diluted  $\text{NH}_4\text{OH}$  (1:20). Ignite it in a tared crucible, at first slowly until the filter paper is charred and then burned off, and finally at 1,050 to 1,100 deg. C. for 30 to 45 minutes. Weigh the residue as  $\text{Mg}_2\text{P}_2\text{O}_7$  and calculate the percentage of MgO as follows

$$\text{MgO, per cent.} = W \times 72.4$$

where  $W$  = weight of  $\text{Mg}_2\text{P}_2\text{O}_7$ .

#### Blank Determination.

6. Make a blank determination for silicon dioxide, aluminium oxide, and ferric oxide, calcium oxide<sup>3</sup> and magnesium oxide, using the same procedures as described in Sections 1, 4 and 5, and using approximately the same amounts of reagents. Correct accordingly the results previously determined.

<sup>3</sup> When the amount of calcium oxalate is very small, its oxidation by  $\text{KMnO}_4$  is slow to start. Before the titration, add a little  $\text{MnSO}_4$  to the solution to catalyze the reaction.

## Pozzolana Cements.

BUILDING Research Technical Paper No. 27, entitled "Investigations on Pozzolanas: I—Pozzolanas and Lime Pozzolana Mixes" (London: H.M. Stationery Office; price 1s. net) deals with mixes of pozzolanas with lime. The term pozzolanic cement is restricted to mixtures of Portland cement and pozzolana, and is not used for mixes of lime and pozzolana. Pozzolanas is defined as siliceous materials, which, though not cementitious in themselves, contain constituents which at ordinary temperatures will combine with lime in the presence of water to form compounds which have a low solubility and possess cementing properties.

Pozzolanas are divided into two separate groups, one consisting of natural pozzolanas and the other of artificial products. With the exception of diatomaceous earth, the natural pozzolanas are volcanic tufts which in many cases have undergone considerable chemical alteration after deposition. The materials best known in Europe are the German trass from the Rhine district and Bavaria, the Italian pozzolanas, Santorin earth from the Grecian isle of Santorin, Tosca imported from Teneriffe, and Tetin from the Azores. Although the greater part of the investigations have related to artificial pozzolanas, comparative tests have also been made on certain natural pozzolanas.

A summary of the report is given as follows:

(1) Investigations have been made on the comparative properties of natural and artificial pozzolanas and on methods for testing pozzolanas.

(2) Measurements of the rate of reaction of pozzolanas with a lime solution, or of the amount of lime becoming combined with a pozzolana in pozzolana-lime mortars, affords in general no indication of the strength developed in pozzolana-lime mortars.

(3) Strength tests on pozzolana-lime mixes may be carried out on mortars of dry or plastic consistency, but the latter is preferred. A suitable consistency test is given. An accelerated strength test in which a plastic mortar is cured for 7 days in moist air at 18 deg. C. followed by 46 hours in water at 50 deg. C. and 2 hours in water at 18 deg. C. has been found to give an estimate of the strength developed in 90 days at ordinary temperatures. Detailed methods for the testing of pozzolanas in mixes with lime are given.

(4) The effect of the pozzolana-lime ratio, the hydrated lime, the fineness of the pozzolana, and the addition of gypsum on the strength developed in pozzolana-lime mortars has been examined. Data are also given on the combined lime contents of pozzolana-lime mortars.

(5) The rate of reaction of pozzolanas with lime, and of the development of strength, increase very markedly with rise in temperature.

(6) Data on the compressive strength of lime-pozzolana concretes, and on similar mixes containing small additions of Portland cement, are given.

(7) Most pozzolanas contain some soluble salts which will contribute to staining of limestone and efflorescences arising from mortars.

(8) Artificial pozzolanas can be produced from burnt clays and shales equal in properties to good natural pozzolana.

## Research on Cement.

THE following notes are from the Report of the Building Research Board for the year 1939. (H.M. Stationery Office. Price 1s. net.)

*The Constituent Compounds of Set Cements.*—The investigation referred to in the last Report on the aqueous quaternary system lime-alumina-calcium sulphate-aluminium sulphate at 25 deg. C. has been completed and published.<sup>1</sup> As only the high sulphate form of calcium sulphoaluminate has been found to occur in this system at 25 deg. C., a further study of the effect of supersaturated lime solutions and of alkali additions was commenced to ascertain the conditions under which the low sulphate form of this compound appears.

The work on the system  $\text{CaO-SiO}_2\text{-H}_2\text{O}$  has been carried further by a detailed X-ray examination which is now approaching completion. A paper has been published on the mechanism of the action causing the fall in strength of high-alumina cement when cured at temperatures above normal.<sup>2</sup> It has been concluded that this fall in strength, which is found with calcium monoaluminate just as with high-alumina cement, is to be ascribed to the inversion of the less basic hydrated calcium aluminates to the cubic tricalcium aluminate hexahydrate.

*Special Cements.*—The work carried out for the British Joint Committee on Special Cements has been concerned with the provision of data required for a draft specification for low-heat cements which the committee has had under consideration. A series of comparative tests on the heat of hydration of cements has been made in collaboration with other members of the International Committee on Special Cements.

*Fineness of Portland Cements.*—A study has been made of an air permeability method for the measurement of the surface area of cements and a paper has been published.<sup>3</sup> This method, which is based on earlier work by Carman<sup>4</sup> on the permeability to liquids of beds of granular materials, has been found to afford a rapid and convenient method for the estimation of the specific surface of fine powders. The specific surface value obtained is higher than that given by the Wagner turbidimeter using the normal arbitrary assumption that the average particle diameter of all particles below  $7.5\mu$  is  $3.8\mu$ , but close to that obtained with the Andreasen sedimentation method when sedimentation is carried down as far as particles of  $0.5\mu$  in diameter and the Andreasen dimension used for defining particle diameter.

<sup>1</sup> Jones, F. E. The Quaternary System  $\text{CaO-Al}_2\text{O}_3\text{-CaSO}_4\text{-H}_2\text{O}$  at 25 deg. C. Trans. Faraday Society, 1939, 35 (12), 1484-1510.

<sup>2</sup> Lea, F. M. The Effect of Temperature on High-alumina Cement. J. Soc. Chem. Ind., Lond., 1940, 59 (1), 18-21T.

<sup>3</sup> Lea, F. M., and R. Nurse. The Specific Surface of Fine Powders. J. Soc. Chem. Ind., Lond., 1939, 58 (9), 278-83. (Build. Sci. Abstr., 1940, No. 15.)

<sup>4</sup> Carman, P. C. Determination of the Specific Surface of Fine Powders. J. Soc. Chem. Ind., Lond., 1938, 57 (7), 225-34; 1939, 58 (1), 1-7.

## Ball-Mill Grinding.\*

**Selection of Volume of Ball Loads in Continuous Dry Open-circuit Grinding.**—The tests reported in Tables 19 and 20 were made in co-operation with a large cement manufacturing company that wished to obtain more grinding for the power expended. The ball load in its clinker-grinding mills was 18 per cent. of the mill volume and the company did not deem it consistent to increase the ball load because the mills, having been pebble mills originally, could not carry a heavier load; also, the ball loads already taxed the motors to their limit. The tests required investigating the ordinary overflow type of mill and the low pulp-level type. The tests shown in *Table 19* anticipated the overflow

TABLE 19.—CONTINUOUS DRY BALL MILLING WITH VARIOUS BALL LOADS.  
(Mill, cylindrical, 19 in. by 36 in. Circuit, continuous, open. Discharge, 4 in. Speed, 60 per cent. critical. Load, balls, 1½ in. Volume, varied. Ore charge, Dolomite B. Consistency, dry.)

Size, mesh	Feed, weight percent	Product, weight percent					
		Ball volume, percent					
		18	25	30	35	40	45
8.....	0.4						
10.....	4.5	0.1	0.1				
14.....	16.4	.3	.2	0.2	0.1	0.1	0.1
20.....	32.6	.7	.4	.3	.3	.4	.3
28.....	47.6	1.5	.7	.6	.7	1.0	.8
35.....	61.0	3.6	1.8	1.5	1.9	2.7	2.2
48.....	73.0	6.8	4.7	4.2	5.2	7.2	6.2
65.....	81.6	13.6	10.4	9.5	11.6	15.1	13.8
100.....	87.6	25.0	21.7	19.9	23.1	27.0	26.0
150.....	91.0	36.4	32.7	31.1	34.2	37.6	37.1
200.....	93.2	46.6	43.6	41.6	45.1	47.1	47.5
—200.....	6.8	53.4	56.4	58.4	54.9	52.9	52.5
Surface tons per horsepower-hour.....		26.8	32.0	33.4	34.2	38.5	36.0
Ton per hour.....		.08	.11	.126	.15	.175	.186
Horsepower.....		.79	1.06	1.20	1.29	1.36	1.45
Ton per horsepower-hour.....		.101	.104	.106	.116	.129	.130
Ore in mill, pounds.....		176	146	139	144	157	138
Ratio ore to balls, weight.....		1:1.8	1:3.0	1:3.8	1:4.3	1:4.5	1:5.8

mill, and those analysed in *Table 20* were expected to illustrate the deportment of the low-pulp-level or quick-discharge mill. All were dry-feed tests. In *Table 19* the ball volume was from 18 to 45 per cent. and the feed rate had to be regulated so that the subsieve sizes in the products were about the same.

No noteworthy difference in type of grind resulted. The recording of capacities is omitted because, obviously, capacity would be low when ball volume was low. The change in efficiency, however, is important. The efficiency of the overflow mill slumped badly when the ball volume was small. This is because the small ball volume left too much space for ore in storage. These variations are shown in the last line but one in *Table 19*, in which is given as

\* Continued from our numbers for April, May, June and July.

nearly correct an estimation of the amount of ore in the mill as could be determined conveniently. The best work was done with 40 per cent. and 45 per cent. ball volumes, the discharge being 4 in. in diameter.

The last line in *Table 19* shows the ratio of weight of ore to weight of balls. This weight relationship is significant because it leads to the conclusion that when the ball volume is small too much power is spent tumbling the ore; with 18 per cent. ball volume more than one-third of the weight of the mixture was ore. Then, also, there is the question whether the action of the balls would be orderly in such a large volume of ore—that is, would not the mill be little more

TABLE 20.—BATCH DRY GRINDING, ORE CHARGE PROPORTIONAL TO BALL LOAD.  
(Mill, cylindrical, 19 in. by 36 in. Circuit, batch. Speed, 60 per cent. critical. Load, balls, 1½ in. Weight, varied. Ore charge, dolomite B. Consistency, dry.)

Size, mesh	Feed, weight percent	Product, weight percent	
		18 percent ball volume, 63 lb. of ore	40 percent ball volume, 117.5 lb. of ore
8	0.4		
10	5.7		
14	23.2		
20	46.3	0.1	0.1
28	65.5	.2	.2
35	78.8	.9	.5
48	87.5	4.9	2.9
65	92.3	14.8	11.1
100	95.3	27.7	25.0
180	96.7	38.0	36.0
200	97.6	48.2	46.3
—200	2.4	51.8	53.7
Surface tons per horsepower-hour		39.3	40.0
Ton per hour		.118	.203
Horsepower		.90	1.57
Ton per horsepower-hour		.131	.129
Time, minutes		13.5	17.4

than a tumbling device to mix ore and balls? Probably disorderly tumbling would result. The importance of a correct ratio of amount of ore to balls is borne out by examination of the results of a test, shown in *Table 20*, in which the grinding had to be in batch so that the ratio of ore to balls could be kept the same for the different ball volumes. When ratios were correct, the 18 per cent. ball volume performed well, although, for reasons already given, it had failed in the open circuit. The type of grinding and the efficiencies were about the same in the two tests. The conclusion was reached that cement-grinding mills with 18 per cent. ball volume were doing poorly if they were of the overflow type. If they were of the low-pulp-level type, and the low-pulp-level devices kept the clinker charge low in accord with manufacturers' claims, the efficiency was not impaired because of the small volume of balls.

**Non-ferrous Media and Steel Balls Compared.**—PEBBLES.—Pebble mills are an important factor in fine grinding. In both wet and dry grinding, pebble

mills have been used on plant problems in the Rolla laboratory and experience with them has overcome some of the early prejudices. One of these arose from the belief that pebbles had to be much larger than steel balls. The results of an experiment in which the balls and pebbles were of the same size, given in *Table 21*, show that dolomite yielded about the same type of grinding with each medium and the efficiency of the pebbles was only 18 per cent. below that of the balls. The pebbles were irregular in shape. Their failure to present spherical surfaces might have reduced their effectiveness. (As is well known, large quantities of quartzite "pebbles" are used in tube mills on the Rand. They are

TABLE 21.—PEBBLES AND BALLS COMPARED.

(Mill, cylindrical, 19 in. by 36 in. Circuit, batch. Speed, 70 per cent. critical. Load, 275 lb. pebbles, 796 lb. balls, Davis No. 1. Volume, 45 per cent. Ore charge, 75 lb. chert and dolomite No. 1. Consistency, 60 per cent. solids.)

Size, mesh	Chert			Dolomite no. 1		
	Feed, weight percent	Product, weight, percent		Feed, weight percent	Product, weight percent	
		Pebbles	Balls		Pebbles	Balls
8.....	1.7	0.1	0.1	0.9	.....	0.1
10.....	25.2	3.9	1.1	15.3	1.4	1.1
14.....	55.0	13.6	5.2	50.8	8.8	9.1
20.....	76.7	29.2	15.0	79.5	24.9	23.9
28.....	87.2	45.1	30.4	90.2	42.4	39.9
35.....	93.4	57.7	48.8	95.4	55.9	55.4
48.....	96.2	67.6	61.0	97.3	65.2	64.2
65.....	97.9	74.6	71.1	98.2	71.3	70.7
100.....	98.9	80.5	78.2	98.6	76.5	76.1
150.....	99.4	84.3	83.3	98.8	80.3	80.4
200.....	99.6	86.8	86.6	99.0	83.3	83.7
-200.....	.4	13.2	13.4	1.0	16.7	16.3
Surface tons per hour.....	12.5	35.2	.....	38.3	108.0	.....
Surface tons per horsepower-hour.....	17.9	21.7	.....	49.1	60.2	.....
Ton per hour.....	.124	.303	.....	.326	.865	.....
Horsepower.....	.70	1.62	.....	.78	1.70	.....
Ton per horsepower-hour.....	.177	.187	.....	.418	.506	.....
Time, minutes.....	18.2	7.5	.....	6.9	2.6	.....

waste sorted out and are effective and economical.) With this adverse disparity must be considered the low density of the pebbles, so that they contributed only 69 per cent. of the total weight of pebbles, ore, and water, all of which required power to impart action to them. In the rod mill with a large discharge (*Tables 3 and 4*) and "rods" with the same density as that of pebbles, the ratio of weight of rods to weight of ore and water was more favourable because of the smaller amount of voids. In *Table 21*, as in *Table 3*, the powers are proportional to the weight of media plus ore plus water.

The results with the chert, shown on the left of *Table 21*, require more critical consideration. Undoubtedly the pebbles failed to grind the coarse material because they were too small or too light. The pebbles failed to grind the coarse chert, whereas the grinding by the balls was about the best on record for the particular speed and charge employed. The balls were known to be the best

size for the chert, and it is apparent that the pebbles should have been larger. If the balls had been smaller and the pebbles had been correspondingly smaller, then the pebbles might have displayed the same deficiency they showed with chert. The tests indicate that pebbles should be larger than balls for a comparable type of grind. The pebbles gave about 37 per cent. of the capacity and about 81 per cent. of the efficiency secured by the balls. The efficiency of pebbles in wet grinding (Table 21) was about the same as that of balls in dry grinding (Table 14).

**SILLIMANITE BALLS.**—A stock of 300 lb. of 1½-in. sillimanite balls was presented by the Champion Spark Plug Co. for grinding tests. They were true spheres, white, and all about the same size. Although native sillimanite has a density of 3.2, the artificial product had a density of only 2.56, this being the lowest density included throughout all the experiments. Another characteristic was the high resilience. As measured by the scleroscope, the hardness was 82. When dropped on a pavement from a height of 20 ft. they would bounce like rubber balls and not suffer damage. The flint pebbles had a higher scleroscope hardness (94) than the sillimanite balls. Jasperoid pebbles, not used in these tests, had a hardness of 102. No effort was made to determine the resistance of the sillimanite balls to wear in the ball mill, but their effectiveness, when compared with steel balls, as a grinding medium was gratifying. As would be expected, the grinding capacity of the sillimanite load was low. This is evidenced by the low horsepower and the long grinding period.

Tests with sillimanite balls could not be carried to a conclusion, and no detailed results are given. The reason for this and for interpreting the tests with the flint pebbles not too rigorously is because of a principle not commonly recognised in grinding tests; that is, when media of different characteristics are to be compared tests must be made with several different sizes of each medium to determine which size is best for the particular particle size and hardness of the ore. At first thought it might seem that ore samples of a variety of particle sizes could be substituted for a variety of ball sizes, but such a transposition is incorrect because it is not known that different particle sizes have the same grindability; in fact, the evidence shows that they do not. Furthermore, it is difficult to be consistent in the amount of work applied to each sample.

(To be continued.)

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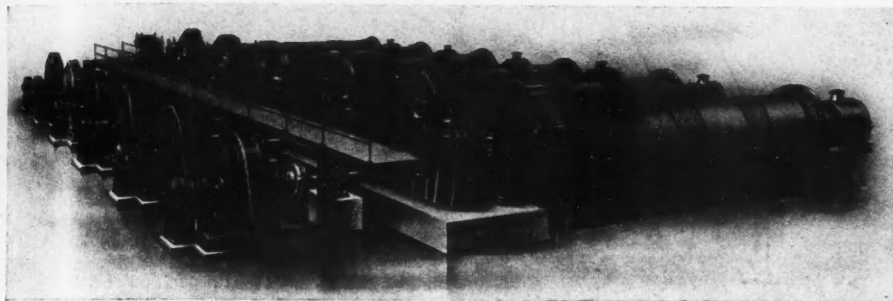
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